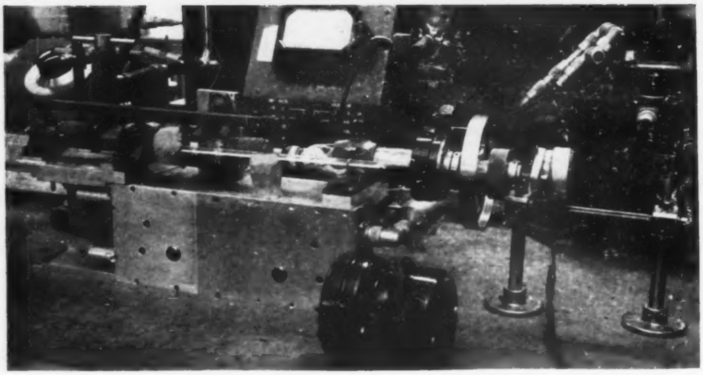
PROPAGATION OF SOUND IN MONATOMIC GASES

MEASUREMENTS of the speed and attenuation of 11-megacycle per second sound waves in monatomic gases were recently completed by the National Bureau of Standards.[1] Data obtained from five gases—helium, neon, argon, krypton, and zenon—have provided new information on the behavior of gases under nonequilibrium conditions, permitting an intercomparison of propagation theories based on "classical" equilibrium assumptions and those based on modern kinetic concepts. Supported in part by the Office of Naval Research, the investigation was conducted by M. Greenspan of the NBS sound laboratory. A double-crystal interferometer in which a number of design improvements have been made was the principal instrument used.

Whereas the immediate purpose of these measurements is to assist in the verification of theories of nonuniform gases, the results have a bearing on upper-atmosphere flight, the propagation of shock waves, and problems of high-speed gas dynamics generally. For example, aerodynamic research has shown that the motion of an aeroplane or missile through the air is decisively affected by conditions in the so-called boundary layer of air immediately surrounding the moving object. This layer is characterized by the occurrence of large changes in pressure and temperature within very short distances, in contrast to the uniformity assumed in classical theories. Thus the classical assumption has proved inadequate for calculating the viscosity of gases surrounding even relatively slowly moving objects. Considerable effort has therefore been made to develop mathematical theories that take the effect of departure from equilibrium into account. The study of sound propagation provides one of the more direct experimental checks on these recent theories.

Translational Dispersion

Under ordinary atmospheric conditions and at audiofrequencies, there is no detectable dispersion of sound; i. e., all these frequencies travel with the same speed. Otherwise, for example, the sounds from a flute and a bass drum, though emitted simultaneously, would not reach the back of the concert hall at the same time. When the frequency is raised sufficiently, however, or if the pressure is correspondingly reduced, an effect known as translational dispersion occurs. Though long expected on the basis of theory, this effect was first detected experimentally by the NBS sound laboratory in 1949.[2]



Double crystal interferometer used in measurements on the propagation of sound in gases. The data obtained provide a check on modern theories of nonuniform gases that are of interest in aerodynamics. Sound at 11 Mc produced by a quartz piezoelectric crystal is sent through the gas under test, is received by another crystal and converted to an electrical signal that can be measured by special circuits. The interferometer rests on an aluminum I-beam which also houses the high-frequency sections of the electrical circuits (concealed by aluminum cover plates).

Translational dispersion can be traced to the nonuniform conditions created by the passage of a sound wave. In one region of the gas, for example, the molecules will be moving with an average speed somewhat in excess of that of the molecules a little farther on in the direction of propagation. Ordinarily the molecular speeds are sufficient to transmit the excess speed as fast as the wave pulses arrive. At extremely high frequencies, however, or at extremely low pressures (when the molecules must travel farther between collisions), only the faster molecules participate in the transmission process. As a result, the higher frequencies travel with greater speed.

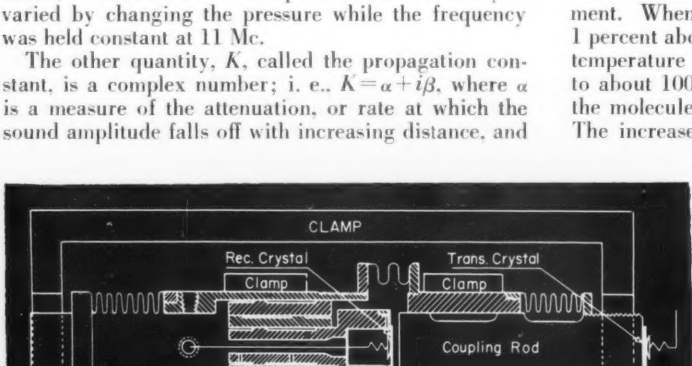
Propagation Theories

In the mathematical theories that have been developed for the transmission of sound in monatomic gases, the equations can be expressed in terms of two variables, r and K. The first of these, r, is a measure of the ratio of the mean frequency of molecular collisions to the sound frequency. In the Bureau's experiments, r was taken as the independent variable and was varied by changing the pressure while the frequency was held constant at 11 Mc.

The other quantity, K, called the propagation constant, is a complex number; i. e., $K=\alpha+i\beta$, where α is a measure of the attenuation, or rate at which the sound amplitude falls off with increasing distance, and β is proportional to the ratio of frequency to speed. Since the frequency was held constant in the present experiments, β could be considered inversely proportional to the speed.

Three theories of sound propagation in monatomic gases were compared with the Bureau's measurements. All of these are based on the assumption that the Boltzmann integrodifferential equation for the distribution of molecular velocity is valid even for the enormous velocity and temperature gradients that occur in the experiments described. The first theory, which represents the classical approach, was originally developed by Kirchhoff, though it is better known as the Stokes-Navier theory in the form here used. The other two, known in the literature as Burnett theories, make use of modern developments in kinetic theory; they were developed by C. S. Wang Chang and G. Uhlenbeck. The first of these (referred to below as "the Burnett theory") is based on equations obtained from a velocity distribution correct in the second approximation. The other theory ("the super-Burnett theory") corresponds in the same way to the third approximation.

For small dispersions, the three theories are in agreement. When $r=8$, the speed of sound should be about 1 percent above its normal value. For helium at room temperature and standard pressure, this corresponds to about 100 Mc and the mean collision frequency of the molecules is about 61 times the sound frequency. The increase in speed is about 10 percent for $r=3$,



Schematic drawing of double-crystal interferometer. Horizontal scale is half vertical scale. Transmitting crystal sends sound waves through metal coupling rod and layer of gas under test into receiving crystal that converts sound into an electrical signal. Transmitting crystal and coupling rod are shifted to change length of sound path in gas, causing changes in phase and amplitude of the received signal from which speed and attenuation of the sound can be determined. Electrical circuits excite transmitter crystal and measure amplitude and phase of received signal.

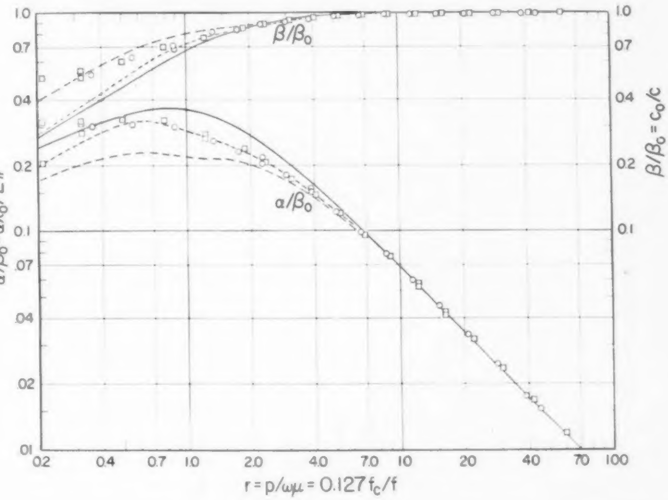
which corresponds to a mean collision frequency about 23 times the sound frequency, or to 260 Mc at room temperature and standard pressure.

Double-Crystal Interferometer

The Bureau's measurements were made with a double-crystal interferometer [3] of the type whose theory was described by W. S. Fry. The instrument was first built in 1950 and was used for studies of the propagation of 1 Mc sound waves in helium. It was later modified to operate at 11 Mc and several improvements in design were made. The changes led to better protection of the gases against contamination, elimination of mechanical cross talk, and improved control of electrical cross talk.

The essential parts of the device are two X-cut quartz crystal transducers for transmitting and receiving 11-Mc sound waves. Electrical circuits are used for exciting the transmitter crystal and for amplifying the received signal and measuring its phase and amplitude. The attenuation and speed of the sound are determined from the changes in amplitude and phase of the received signal when the length of the sound path is altered by shifting the transmitter crystal.

Although called an interferometer, the instrument is not operated in the interference region, but under conditions that make the standing waves between the crystals practically negligible. Under such conditions the received phase varies linearly and the received amplitude exponentially with the length of the sound path. The amplitude is presented by a recorder having a logarithmic characteristic, and the phase by a conventional recorder. As a result, when the recorders are driven synchronously with the motion of the transmitter crystal, the slopes of the straight-line records give directly the attenuation and velocity of sound in the medium.



Graph showing results of measurements on the propagation of 11-Mc/sec sound through neon (circles) and argon (squares). The curves show predicted values according to the Stokes-Navier theory (solid line), the Burnett theory (short dashes), and the super-Burnett theory (long dashes). Upper curves (use right-hand ordinate scale) represent a quantity (β) that varies inversely with the speed; β_0 is a constant equal to the value of β under ordinary conditions. Lower curves (use left-hand ordinate scale) represent the attenuation. The abscissa, r, is proportional to the ratio of the mean collision frequency (f_c) of the gas molecules to the frequency (f) of the sound. Note that an increase in β represents a decrease in speed, while an increase in r may be interpreted as either an increase in pressure or a decrease in frequency.

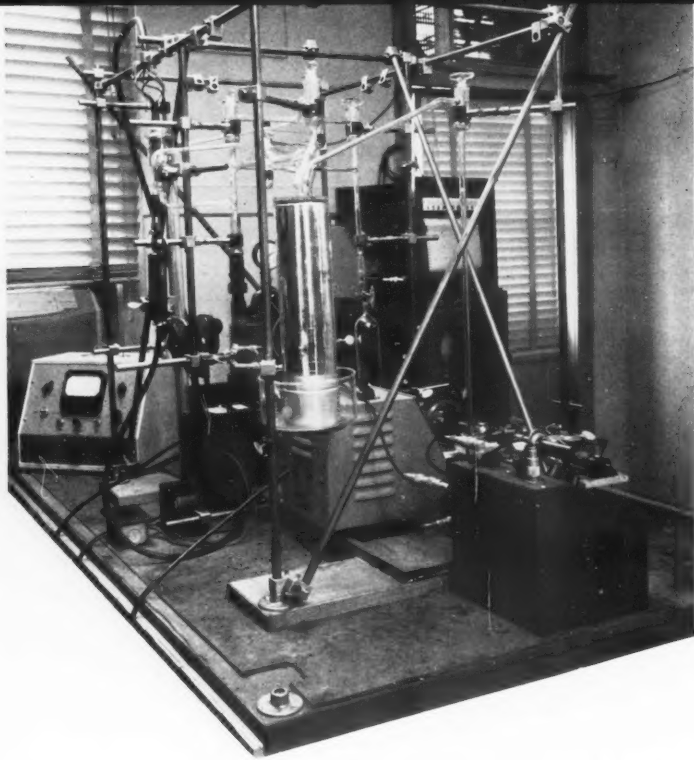
Experimental Results

The measurements show that all five gases behave in substantially the same way at 11 Mc. In the range for which dispersion is negligible (r greater than about 10) and for which the various theories are nearly indistinguishable, the measured values agree with the calculated ones very closely. For this range, then, the classical theory gives as good results as the modern theories.

For r less than 10, the Burnett theory showed the best agreement with experiment. This theory appears to give a satisfactory account of the velocity of sound for r greater than about 1, and of attentuation for r greater than about 0.5.

The fact that the Burnett theory agrees better with experiment than does the super-Burnett theory may at first seem surprising. However, even before the Bureau's measurements were made, it was suspected that the Burnett theories based on successively higher order approximations to the velocity distribution would alternately approach and recede from the correct result. The present measurements therefore raise a convergence question with respect to the method of expanding the distribution function.

A number of efforts have recently been made to improve the theory. A Burnett theory demands complex and troublesome manipulation of the nonlinear Boltzmann equation; the final results are linearized by assuming the amplitude of the sound waves to be small. Being unsatisfied with this, Wang Chang and Uhlenbeck and, independently, Mott-Smith have introduced the assumption of small amplitude and the consequent linearization directly in Boltzmann's equation. Unfortunately, this leads to a series development that is not useful for small values of r. Pekeris has attempted to correct this defect by resorting to a succession of approximations, each in turn the root of a polynomial



General view of apparatus used in studies of sound propagation through gases. Glasswork superstructure and meter (left, rear) control and measure pressure of the test gas in the double-crystal interferometer partly visible (right, rear) on the table. Cabinet in rear houses most of the electrical circuits for measuring the phase and amplitude of sound that has traversed the test gas. Resting on the cabinet is the instrument for recording the sound amplitude.

of higher degree. The roots are obtained by numerical methods and the convergence is to be judged by the spread of successive results. Much interesting work on new methods of solving the Boltzmann equation has also been done at the N. Y. U. Institute for Applied Mathematics and Mechanics, though the application of this work to sound propagation is not yet available.

Thermal Relaxation

The Bureau's studies of monatomic gases are intended as part of a larger program to accumulate data on the dispersion of sound in various gases and mixtures of gases and to correlate these data with the available theories. Preliminary measurements have already been made in air, oxygen, nitrogen, and hydrogen. In such polyatomic gases and mixtures, another source of dispersion—thermal relaxation—is present in addition to that found in monatomic gases. This too is a consequence of nonuniformities in the gaseous medium.

In polyatomic molecules, energy is stored in the form of rotation or vibration (or both) as well as in the form of kinetic energy of translation. Under equilibrium conditions the energy is shared by these different modes in accordance with the law of equipartition of energy. During the passage of a sound wave, however, energy is transmitted first in the form of kinetic energy of translation; and a period of time must elapse before this is shared with the rotational and then with the vibrational modes. In carbon dioxide, for example, it requires about 60,000 mean collision intervals for the energy to be transferred to the vibrational modes. Hence, as the ratio of sound frequency to collision frequency rises, the proportion of energy in the translational form increases and the sound wave is transmitted with correspondingly greater speed.

It was found in the Bureau's preliminary studies that rotational dispersion in oxygen and nitrogen occurs at frequency-to-pressure ratios so high that they overlap those associated with translational dispersion. A theory of the combined effect of the two sources of dispersion was therefore developed [4] so that the data could be properly interpreted.

Vibrational dispersion in carbon dioxide and other linear triatomic molecules has been thoroughly studied by a number of investigators. Rotational dispersion, however, such as occurs in oxygen and nitrogen, has only been touched upon because the relevant frequency-to-pressure ratios are beyond the range of hitherto existing quipment. The relaxation-time data obtainable from sound propagation studies of these components of air would have immediate application to practical shock-wave problems and high-speed upper-atmosphere flight.

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[1] *For further technical details, see* Propagation of sound in five monatomic gases, *by M. Greenspan, J. Acoust. Soc. Am.* **28** *(July 1956)*.

[2] Propagation of sound in rarefied helium, *by M. Greenspan, J. Acoust. Soc. Am.* **22**, *568 (Sept. 1950)*.

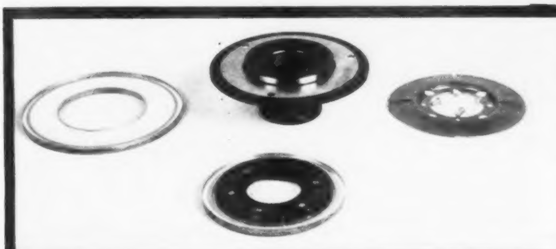
[3] An eleven megacycle interferometer for low pressure gases, *by M. Greenspan and M. C. Thompson, Jr., J. Acoust. Soc. Am.* **25**, *92 (Jan. 1953)*.

[4] Combined translational and relaxational dispersion of sound in gases, *by M. Greenspan, J. Acoust, Soc. Am.* **26**, *70 (Jan. 1954)*.

PRECISION ETCHING OF GLASS SCALES

INFORMATION on a number of improved techniques for producing precise etched glass scales has recently been made available by the Bureau.[1] Methods for the domestic manufacture of high-precision graduated glass circles and reticules for theodolites were developed by Raymond Davis and Chester I. Pope of the Bureau staff at the request of the U. S. Army Engineering Board. The techniques may also be applied to the manufacture of glass scales for optical measuring instruments such as dividing heads, indexing tables, cam-rise gages, and the like.

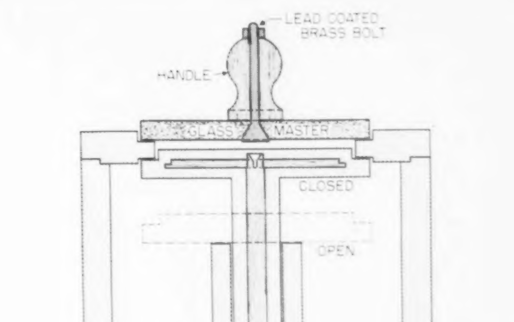
Theodolites equipped with glass scales were not manufactured in this country at the time the Bureau initiated its studies. Although the etching of glass has been widely practiced for a number of years, there was no information generally available for etching the high-precision glass circles required by theodolites. These



Top: **Reticule-ruling machine places lines with accuracy of $\pm 1\ \mu$. Graduated drum adjoining hand wheel may be read to $1\ \mu$. Table attachment for holding reticules has longitudinal and crosswise adjustment as well as a divided circle with vernier and tangent screws for angular positioning.** ***Left:*** **Theodolite glass circles and mounts. Vertical ring (foreground) and horizontal circle (left) are etched with minute graduated lines and numbers.** ***Below:*** **Wax pot for vapor etching of glass scales. The center unit is lowered by means of counterweights to expose glass master in position on top of pot.**

circles are read by means of a micrometer microscope so constructed that a 4-in. circle can be read to 1 sec of angle. A graduation displaced by 0.00001 in. would cause an error of 1 sec in the reading. Thus the precision required is extremely high and difficult to achieve.

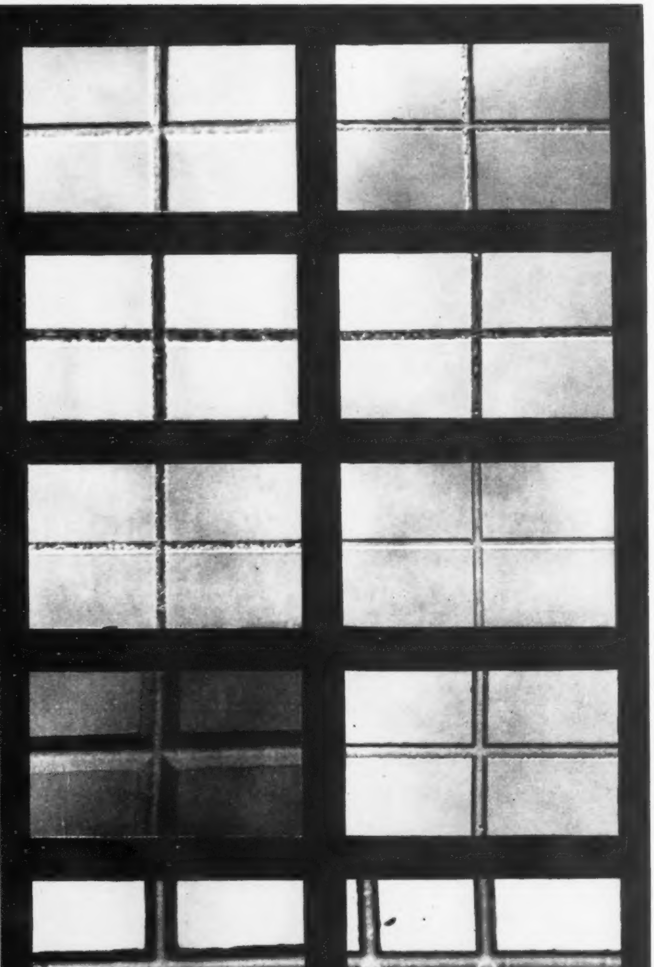
In the course of its investigations, the Bureau developed two methods for producing very precisely graduated and numbered glass circles. The steps required by the basic method include coating the glass with a wax resist, engraving, etching, removing the resist, and filling the etched areas. The second technique is a rapid "photographic" procedure designed to produce replicate scales from glass circles produced by the basic method. In the photographic method, the glass circle, coated with a light-sensitive resist, is contact-printed with an optically flat master. The circle is then "developed" by applying a solvent which dissolves out the unexposed portions without attacking the exposed areas. The latter have been rendered insoluble by the action of light. The remaining operations are slightly modified from those of the basic method to compensate for differences in the light-sensitive resist.



SECTION THROUGH WAX ETCHING POT

Resists

A considerable portion of the Bureau's study was devoted to the formulation of a number of wax and light-sensitive resists. Although waxes are resistant



Photomicrographs showing influence of amino silane on etching solutions. The six pairs of glass pieces have been etched with six different etching solutions. The right-hand pieces of each pair were waterproofed with amino silane before coating with resist.

to hydrofluoric acid, they cannot always be cleanly engraved. The addition of other materials such as rosin, resin, pitch, and asphalt improves the resist's engraving characteristics but may reduce adhesion to glass or resistance to acid. However, several resists were developed which are composed of both natural and synthetic materials and have none of the undesirable properties.

A resist can be applied in either of two ways. In the simpler method, the glass piece is set spinning on a whirler. Then the resist is heated and flowed onto the whirling glass piece. A more uniform coating, free from impurities or lint, is produced by the "pull-out" method, where the circle is submerged in a benzene-resist solution and withdrawn at a constant rate by mechanical means. Other factors affect the quality of a resist: A temperature change of 10° to 20° F is likely to reduce the bond to the glass, and a resist will not adhere to a glass surface that is not carefully cleaned and dried. Comparisons showed that treating the glass with amino silane prevents the resist from lifting during etching and also produces sharper lines.

Engraving

Two Bureau-designed engraving machines aided the development of the glass etching techniques. One is a reticule-ruling and measuring machine for engraving the glass circles. It was also used to test ruling properties of experimental resist formulations. The other instrument is a pantograph which numbers the graduations. Ruling and scribing tools used with these instruments are made from diamond or steel. The steel tools for engraving graduations are high-carbon steel drill rod hardened by heat-treating.

Etching

After the coating on the glass is engraved, the glass piece is etched by gaseous hydrogen fluoride (either dry or moist) or with an aqueous solution of hydrofluoric acid. Gas etching produces a matte finish and is used principally for etching fine lines that will not be filled with pigment. Etching by gas requires a relatively longer time and is thus more easily controlled. Etching solutions produce a clear etch or a frosted etch, depending on their compositions. Those solutions giving a clear etch generally contain 48 to 60 percent hydrofluoric acid; those that give a frosted etch contain salts that promote the formation of insoluble compounds on the glass surface. Concentrated hydrofluoric acid solutions are too fast to control when etching fine lines. However, hydrofluoric and phosphoric acid combined produce a mild solution which can be controlled for etching very fine graduations.

Photoetching

The "photographic" method developed by the Bureau prepares replicate glass circles from a master circle made by the usual procedure. The photographic

method is much faster as no mechanical engraving is required. In this method, a light-sensitive coating is applied to a glass circle which is then contact-printed with the master "negative" and "developed." The coating consists of phenol-formaldehyde resin with iodoform as a sensitizer. The addition of resorcinol-formaldehyde resin improves the light-sensitive qualities of the coating.

The light-sensitive resin is applied to the glass by the "pull-out" method with special precautions to ensure a very uniform, thin coating. A cabinet of special design was constructed for contact-printing a design on the resin-coated circle from the glass master. After exposure, the unexposed areas are dissolved out by a solution containing methyl ethyl ketone, butyl alcohol, and ethyl alcohol. The circle is then baked to increase the resistance of the developed resin coating to hydrofluoric acid. The best etching results are obtained with an aqueous mixture of hydrofluoric and phosphoric acids.

The Bureau also studied the effect of relative humidity on the deterioration of phenol-formaldehyde and cold-top enamel resists. Excellent results have been obtained with the resins developed for the photographic process. Graduation lines on the replicate circles are about 1 μ wider than those on the master circle.

[1] *For further technical details, see* Techniques for ruling and etching precise scales in glass and their reproduction by photoetching with a new light-sensitive resist, *by R. Davis and C. I. Pope, NBS Circular 565, available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., 30 cents.*

REVISED BUILDING CODE FOR MINIMUM DESIGN LOADS

THE American Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, sponsored by NBS and approved by the American Standards Association, is now available in the 1955 revision. For many years this standard has been a source of information for states and cities in formulating their building and safety codes.

This document is one of a series of related Standards presenting basic building code requirements that are being developed by technical committees under the procedure of the American Standards Association. First issued in 1945, it was revised to include the results of new research and experience and to allow for new construction practices, materials, and techniques. The most significant change in the revision is the inclusion of design requirements for signs, radio and television towers, and other structures.

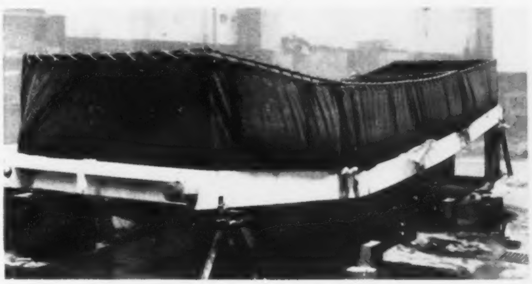
The Standard gives suggested design requirements for live, dead, wind, snow, and earthquake loads. For wind loads, improved requirements are included based upon U. S. Weather Bureau data rather than on acceptance of conventional values of obscure origin. Provision is also made for suction effects based on observation and laboratory experiment. Existing codes only occasionally recognize suction effects.

Early in the process of revision the need for indication of probable wind pressures in different parts of the country was recognized. Consequently, a map delineating wind pressures by areas throughout the country was developed with the aid of the United States Weather Bureau. This map is in the new Standard.

In revising the Standard, past experience with wind storms was only one matter that had to be investigated. Questions arose as to the effect of gusts, the increase of wind velocity with height above ground, and the effect of shape of special types of structures, on the pressures produced on them. These and other matters proved to be so complex that a special American Standards Association subcommittee for further study of wind effects was appointed. Present plans envision inclusion of the results of the subcommittee's study in the next revision of the Standard.

Design requirements for earthquake resistance in the revised Standard are in close agreement with recommended requirements of the Uniform Building Code sponsored by the Pacific Coast Building Officials Conference. Again, it is expected that continued accumulation of data and further research will lead to improved requirements as successive editions are issued.

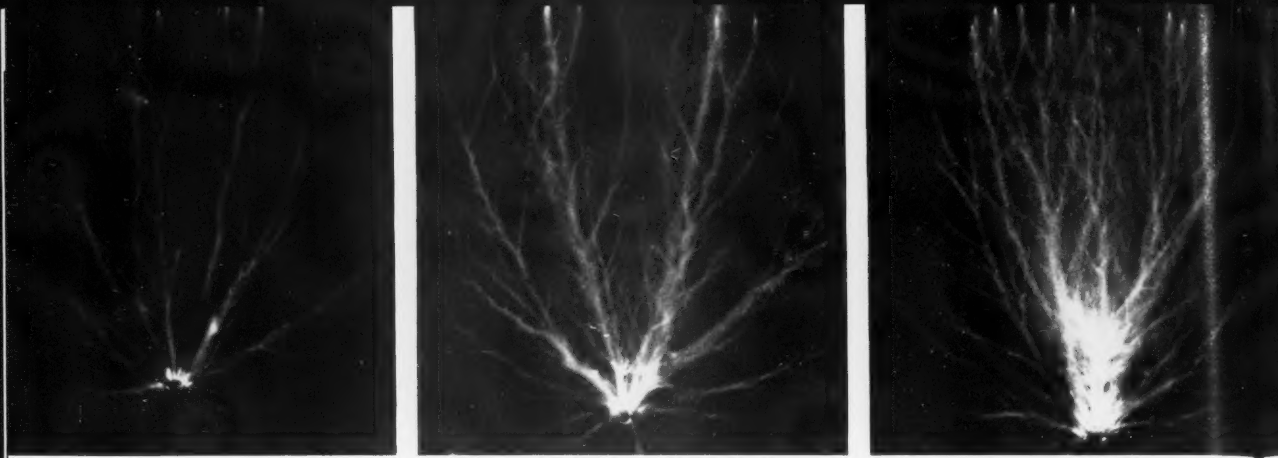
Few changes have been made in those parts of the revised Standard related to snow loads. Those sections in which weights of building materials and loads caused by occupancy are presented in terms of weight per square foot have been carefully reviewed and are believed to provide a sound basis for design.



The roof slab panel shown here is loaded to 80 lb/ft^2, equivalent to about $2\frac{1}{2}$ times the probable snow load for Boston, Mass.

The appendix gives further explanation of how the requirements in the Standard are derived. As an example, for more effective use of the requirements for earthquake resistance, a discussion of earthquakes in the United States is included in conjunction with a table of important earthquakes in the United States and adjoining regions. This table was prepared by the United States Coast and Geodetic Survey.

The 1955 revision is available from the American Standards Association, 70 East 45th Street, New York 17, N. Y. Its cost is $1.50.



SURGE VOLTAGE BREAKDOWN

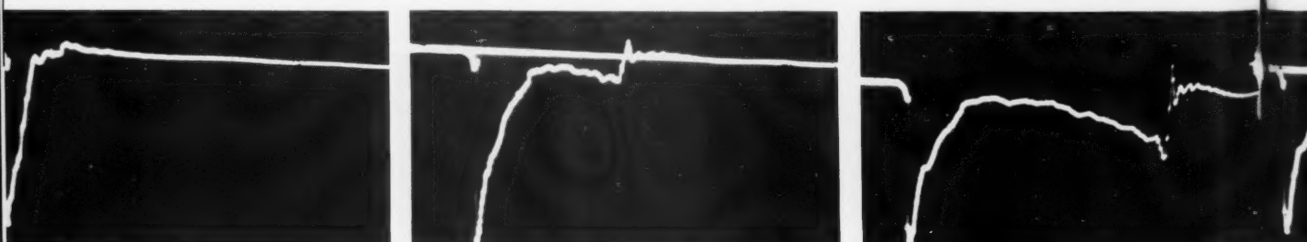
A KNOWLEDGE of high-voltage discharge phenomena is of primary importance in the design of electrical equipment. For example, an understanding of electrical breakdown in air makes possible accurate determination of safe and economic insulation requirements for high-voltage transformers and other apparatus. Information on discharge mechanisms is also of considerable value in electrical surge measurements carried out to provide data for the design of power systems.

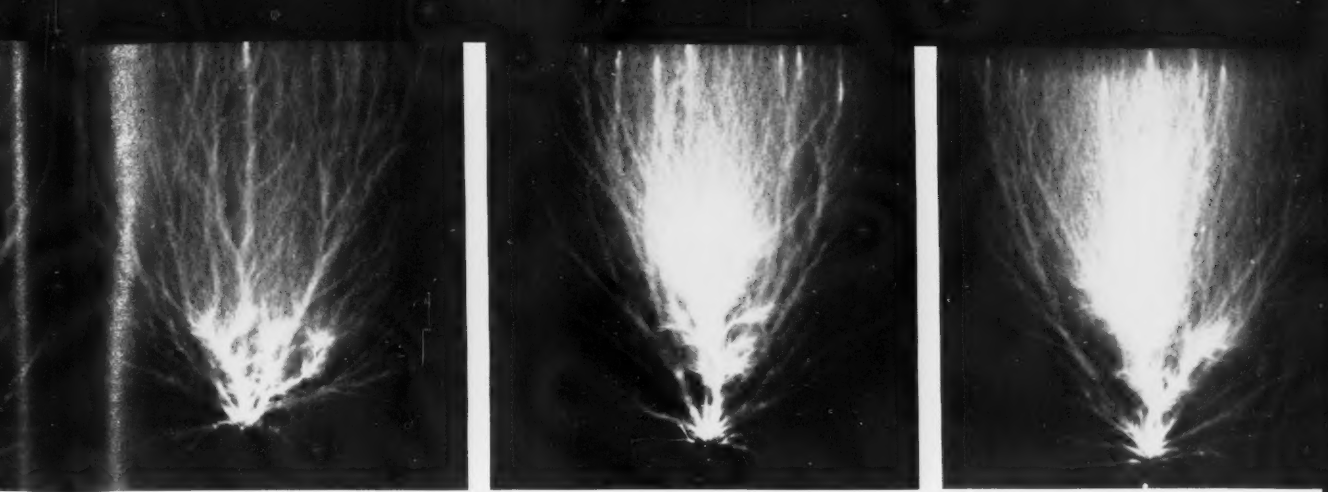
Although several acceptable theories of breakdown in a uniform field have been developed,[1] the much more common problem of nonuniform field breakdown has been relatively unexplored. To provide data on this process, an investigation was recently conducted by J. H. Park and H. N. Cones of the National Bureau of Standards.[2] Their results verify a difference, suggested by the data of earlier experimenters, between breakdown mechanisms in uniform and nonuniform fields.

Cathode ray oscilloscope records and photographs of the discharges obtained by the Bureau reveal that in a nonuniform field discharge streamers (corona) are initiated by a sudden current rise (the first discharge pip). This current quickly decreases, remaining near zero unless complete breakdown is to occur. For gap lengths sufficiently short or for voltages sufficiently high, the first discharge pip is followed by a second rise in current which increases until breakdown occurs. Polarity affects the gap spacing at which breakdown or discharge streamers occur and the speed of formation of these streamers.

The tests were conducted under usual laboratory conditions of pressure and humidity, and the nonuniform field was obtained by using electrodes of dissimilar geometry. The high-voltage electrode consisted of a circular plane, 84 cm in diameter, made of an aluminum alloy. It was placed 86.4 cm above and parallel to the laboratory floor, which had a grounded metal grid imbedded in its surface and was used as a ground plane. The ground electrode was a sphere, 1.6 cm in diameter, mounted at the end of a conductor and located an adjustable distance beneath the center of the high-voltage plane electrode. The conductor, centered in a grounded tube, was connected to a coaxial cable, which terminated at a cathode ray oscillograph. This arrangement permitted an accurate measurement of prebreakdown current and computation of the initial electrical field.

Discharge phenomena were studied by holding the peak voltage of the applied surge at 145 kv and changing the gap spacing. Data were obtained under four conditions of applied voltage: A steeply rising surge with the sphere positive, a slowly rising surge with the sphere positive, a steeply rising surge with the sphere negative, and a slowly rising surge with the sphere





AIR IN A NONUNIFORM FIELD

negative. For gap spacings less than 28 cm when the sphere is positive or 15 cm when the sphere is negative, complete breakdown between sphere and plane usually takes place.

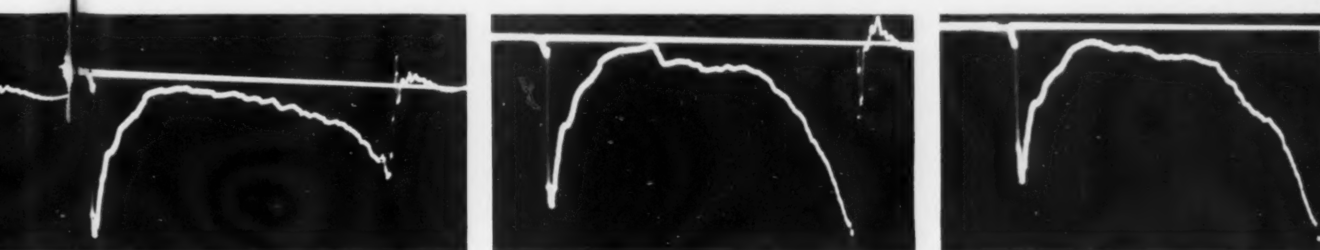
The first discharge pip appeared at gap spacings up to 56 cm for a positive sphere and 46 cm for a negative sphere, but at these large spacings time delays were erratic. At gap spacings less than 46 cm with the sphere positive and 30 cm with the sphere negative a discharge generally appeared with little time lag—less than 0.1 μsec for a steeply rising surge and less than 1 μsec for a slowly rising surge.

In a case where breakdown would ordinarily occur, chopping the voltage after the first discharge rise prevented breakdown. The initial streamer patterns that formed when the voltage was chopped were similar in appearance to those obtained when there was no second discharge rise. In calculating the propagation velocity of the streamers, their length was determined from photographs, and their time of formation was taken as the interval between the start of the first discharge pip and the chopping. The mean streamer propagation velocity is 500 cm/μsec for sphere negative and 800 cm/μsec for sphere positive.

An analysis of streamer formation and channel development provides a more complete explanation of the mechanism leading to breakdown. Streamer photographs show where regions of high charge density have traveled from the sphere to the plane along the lines of force of the applied field. When the sphere is positive, a negative ion situated in the high-field region near the sphere can supply a free electron, which in ionizing neutral molecules forms an electron avalanche. The ionization or recombination process furnishes photons that liberate electrons in the nearby field. These electrons are attracted to the sphere, leaving regions of high positive space charge density near the surface of the sphere. The photo electrons liberated in the volume immediately ahead of the charged region are attracted to it so that the positive region moves from the sphere to the plate, creating a positive streamer.

If the initial streamer pattern produces a sufficiently high gradient, a channel starts to develop at the rate of 3 cm/μsec. As this channel forms, it serves as a good conductor from its origin at the sphere to its leading end. Breakdown takes place along a zigzag channel that has completely spanned the gap.

Pictures (top) and corresponding oscilligrams (below) of streamer development in a nonuniform field, obtained in a study of electrical breakdown by the Bureau. The streamer was initiated by a steeply-rising surge of 145 kv from a positive sphere at a gap spacing of 20 cm. The voltage was chopped at various times after the first current pip to show the discharge as it would appear at successive intervals.



Complete breakdown resulting from a streamer initiated by a steeply-rising surge of 145 kv from a positive sphere at a gap spacing of 20 cm.

When the sphere is negative, the electron avalanches formed in the region near the sphere travel toward the plate where they initiate positive streamers from the plate to the sphere. Electrons are then released from the sphere by high-energy photons impinging on it, positive ion bombardment, or field emission. Negative streamers are formed in much the same way as the positive ones, but in this case electrons repelled from the sphere cause a negative region to move toward the plate.

A positive streamer has a higher velocity of propagation than a negative streamer because electrons move in the direction of the increasing gradient so that the electron avalanches develop faster. The positive streamer can be initiated over a longer gap than the negative streamer because avalanches can form positive streamers for lower applied gradients near the sphere when the sphere is positive.

For the negative sphere, a conducting channel starts out perpendicular to the plane but after a short distance changes its course and makes a zigzag path to the sphere. These channels either contact the sphere or connect with a channel development from the sphere. For shorter gap spacing or considerable overvoltage, breakdown occurs when an initial streamer develops into a conducting channel. The breakdown path is then less zizag, seeming to follow a line of force.

[1] Basic process of gaseous electronics, *by L. B. Loeb, ch. VIII and IX (Univ. of California Press, 1955)*; Theory of gaseous conduction and electronics, *by F. A. Maxfield and R. R. Benedict, page 270 (McGraw-Hill Book Co., Inc., New York, N. Y., 1941)*; *and* The mechanism of the electric spark, *by L. B. Loeb and J. M. Meek (Stanford University Press, 1941)*.

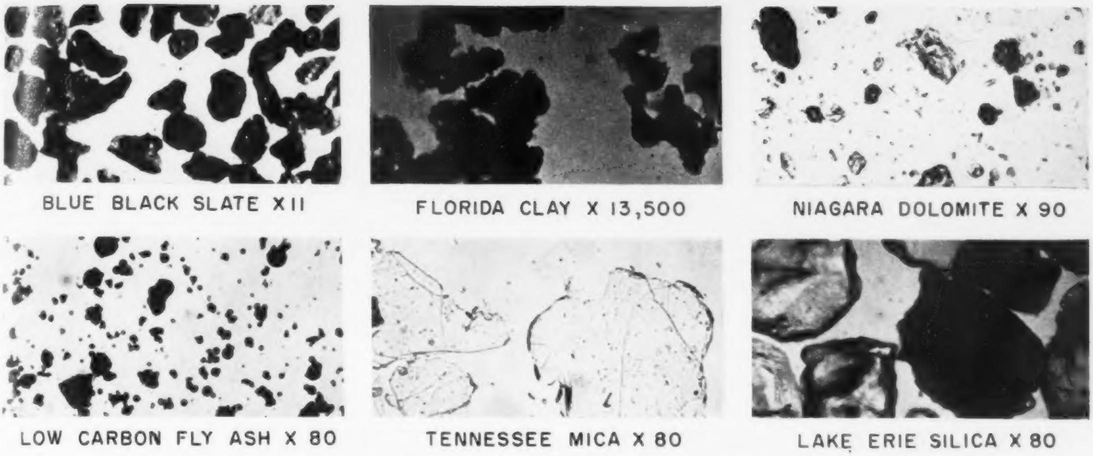
[2] *For further technical details, see* Surge voltage breakdown of air in a nonuniform field, *by J. H. Park and H. N. Cones, J. Research NBS* **56**, *201 (April 1956)*.

Durability of Asphalts Containing Mineral Additives

A STUDY of the weathering resistance of asphalts containing finely divided mineral additives has recently been completed at the Bureau. Results indicate that additives such as mica, blue-black slate, and oyster shell can significantly prolong the service life of roofing-grade asphalt. Three roofing asphalts, representative of three major sources in this country, and 14 different mineral additives were included in the study conducted by S. H. Greenfeld of the Asphalt Roofing Industry Bureau's Research Associateship at NBS.

Earlier investigations elsewhere have indicated that mineral additives, in concentrations up to 35 percent, can increase the durability of the asphalts widely used for roofing materials. Since the time of these investigations there have been many technological advances in the production of asphalt and roofing products. These advances have raised numerous questions concerning how the new materials and methods could be used most effectively in manufacturing roofing of optimum quality. One important area that needed investigation was that of weathering resistance, especially for those asphalts containing mineral additives. Because actual service evaluation of such materials takes so long—up to 20 years for finished roofing—accelerated weathering tests have been developed that can be made in the laboratory. These tests are performed in an "accelerated durability" machine, which is simply a rotating drum in which specimens can be exposed to controlled conditions of heat, light, and water spray. The Bureau used such equipment in the present investigation.

Combinations of asphalts and additives were investigated to find how the durability varied with (1) additive concentration; (2) film thickness; (3) particle size, shape, and distribution; (4) natural variations in



Photomicrographs of six mineral additives used in the investigation of the durability of asphalt.

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similar minerals from different sources; and (5) thoroughness of mixing. Replicate specimens of each coating, 15 to 45 mils thick, were prepared on aluminum panels by the hydraulic press method and were then exposed to an accelerated weathering cycle. This cycle consisted of a sequence of 51 min of light followed by 9 min of light and cold-water spray, repeated 22 hr each day. The specimens were exposed until failure, arbitrarily taken as the time when breaks appeared in 50 percent or more of the coating area.

Results of the investigation show that durability is a function of both asphalt and mineral additives, and that different additives produce different effects on the three asphalts. The asphalt seemed to be the more important of the two ingredients, for all of the additives increased the durability of the asphalts that would normally weather well, while only certain additives increased the durability of the poorer-weathering asphalt. In all instances, durability increased with film thickness.

Those mineral particles with flat, plate-like shapes, such as mica, blue-black slate, and oyster shell, were most effective in increasing the weathering resistance of all three asphalts. Silica, with nearly cubic particles, was among the additives producing the least increase in durability of the coatings. Additives between the extremes of flat and cubic, such as dolomite and fly ash, produced intermediate effects.

Distributions of particle sizes are important in realizing optimum benefits of the minerals. Size distributions were evaluated for three additives: blue-black slate, dolomite, and silica. The 200-mesh size was the most effective, and the distribution between 60 and 200 mesh was least effective in increasing the coating durability. Whereas the effects were apparent at concentrations of 35 percent in the 25-mil coatings, they became pronounced at 50 percent, especially in the 13-mil coatings. It was also noted that relatively small amounts of coarse matter in the 13-mil coatings greatly decreased the weathering resistance and produced unpredictable results.

Natural variations in the clays, fly ashes, and silicas from different sources showed but slight differences in the experimental results. However, one specimen of silica, distinguished by its fine degree of subdivision, was significantly more effective than the other three silicas investigated, although none of them appreciably increased the durability.

It was found necessary to disperse the additive thoroughly and completely throughout the asphalt to obtain uniform results. Any mixing procedure that produced less than complete dispersal resulted in a wider-than-normal spread in durability among replicate specimens.

When asphalts without additives were exposed, it was found that the durabilities of each of the products of each asphalt were inversely proportional to their softening points. However, this greater durability of the softer products was not significant in coatings containing additives; coatings made with softer-base products were not more durable than those made with harder-base products of each asphalt.

For further technical details, see The effects of mineral additives on the durability of coating grade roofing asphalts, *by S. H. Greenfeld, BMS 147 (in press).*

Additional work at the Bureau on asphalts may be found in The effect of mineral fillers on the serviceability of coating asphalts, *by O. G. Strieter, Proc. Am. Soc. Testing Materials* **36**, *II, 486 (1936)*; Weathering tests of filled coating asphalts, *by O. G. Strieter, J. Research NBS* **20**, *159 (1938)*; The effects of exposure conditions on the accelerated durability testing of asphalts, *by L. R. Kleinschmidt and S. H. Greenfeld, Am. Soc. Testing Materials Bul. 214 (April 1956)*; Effects of thermal shock on the durability of asphalt coatings under accelerated test, *by S. H. Greenfeld, Am. Soc. Testing Materials Bul. 193, 46 (1953)*; A method for preparing uniform films of bituminous materials, *by S. H. Greenfeld, Am. Soc. Testing Materials Bul. 193, 50 (1953)*; Asphalt durability test method, *NBS Tech. News Bul.* **39**, *165 (December 1955).*

Summer Careers for Science Students

IN AN EFFORT to meet its increasing demand for high-caliber technical graduates, the Bureau is giving students an opportunity to become acquainted with a Government research laboratory during their undergraduate summers and discover the advantages of a professional career at the Bureau. Open to physical science or engineering majors and also to selected high-school graduates who have displayed unusual scientific ability, the Student Trainee Program is proving mutually beneficial to the Bureau and the trainees. Approximately 150 students have been employed annually since the program was initiated in 1948. Besides carrying their share of the work load during the summer, many fulfill the ultimate aim of the program and later return to the staff in a permanent capacity.

During a summer in the training program a young scientist learns to apply his education in a job selected in accordance with his interests, and broadens his experience by becoming acquainted with other types of work being carried on in Bureau laboratories. Fields of research range from nuclear physics to building technology, and include such projects as the development of a panoramic dental X-ray machine; the redetermination of *g*, the acceleration due to gravity; and studies at the NBS Boulder Laboratories on radio propagation by forward scatter techniques. This diversity of work permits the summer student to participate in his particular field of concentration and to choose a satisfactory assignment if he returns after completing his technical training.

The Student Trainee Program supplements on-the-job experience with a series of tours and lectures designed to familiarize the summer employee with the functions of the Bureau, the scope of its work, and the opportunities it offers. The 1956 program included a general visit to several laboratories, including the Low Temperature, Spectrochemistry, and Radiometry Sections. Students were also given the opportunity to see other projects in which they indicated interest, to tour thoroughly the division to which they were assigned, and to participate in staff panels and meetings. They also attended weekly orientation talks by the Director and Associate Directors of the Bureau and selected staff members.

TABLE 1. *Distribution of students in the summer training program by grade level*

Grade levels	Number of students [a]		
	1954	1955	1956
GS-1	17	21	16
GS-2	17	31	30
GS-3	18	20	62
GS-4	34	24	49
GS-5	16	40	51
GS-7	14	10	15
GS-9	4	2	6

[a] Statistics for 1956 include trainees employed at NBS Boulder.

Alan Haught was the top Westinghouse Science Talent Search winner in 1954 and is now a student in chemistry at Amherst. While at the Bureau, Mr. Haught was successful in reducing the drift in a flame photometer. This instrument permits detection of unknowns in solutions vaporized in a high-temperature flame. Decreasing the drift between readings increased the precision of measurement.

To gain eligibility on the register from which appointments to the program are made, college men and women must pass a written Civil Service examination for student trainees. At the high-school level a limited number of direct appointments are offered winners in the Westinghouse Science Talent Search and other science competitions. A student who has taken part in the

TABLE 2. *Distribution of students in the summer training program by major fields of study*

Major fields	Number of students		
	1954	1955	1956
Physics	46	69	98
Chemistry	30	34	41
Engineering:			
Aeronautical	2	1	1
Ceramic	----	----	1
Chemical	4	1	1
Civil	2	----	1
Electrical	8	13	18
Electronic	----	4	15
Mechanical	14	13	13
Physical	1	2	----
Unclassified	----	----	1
Mathematics	6	6	17
Metallurgy	1	3	5
Biology	1	----	----
Geology	1	1	----
Ceramics	----	1	----
Pulp and Paper Technology	----	----	1
Psychology	----	----	1

Laurie Jean Eveleth of Trinity College, Washington, D. C., is measuring the resistance of cloth samples with an electrometer. Retention of static charge is a direct function of the electrical resistivity and can create a spark hazard under certain conditions. Samples of materials treated to decrease electrical resistance are seen hanging in the constant-humidity cabinet in the upper left of the photograph.

program and is recommended by his supervisor may return each summer while he is completing his education. Participating in the program for the first time this summer were 92 students, from 50 colleges, and 15 Science Talent winners. Of last year's 148 summer scientists, 80 returned to work this summer. At the laboratory in Boulder, Colorado, where the program has just been adopted, 42 trainees were employed.

Salaries are commensurate with the educational level of the applicant, starting at $2,690 per year for high-school graduates entering at the GS–1 level, and progressing to $3,415 for GS–4 employees who have completed the junior year in college (table 1). Graduates who return to the Bureau receive a GS–5 rating, $4,480, and those who are employed in a permanent capacity are advanced to a grade 7, $5,335, after 3 months if they have qualified under a special training agreement during the preceding summer. Graduate students are also accepted for summer employment, a master's degree qualifying scientists or engineers for a GS–7, and half the required Ph.D. work for a GS–9, at $6,250.

The training officer and a group of 12 advisers, one for each technical division at the Bureau's Washington laboratories, supervise the orientation program and act as counselors to the young people. Project leaders are expected to give challenging, nonroutine assignments to students in the training program.

One such assignment was that of Donald Hensler of Dartmouth College, who conducted performance tests on instruments that detect and measure radiation levels. He investigated the stability of transistors and metal diodes under strong radiation fields, and in this way made possible the selection of power-supply components that function best in compact radiological equipment.

Several students have had papers published on the research they did at the Bureau. Ronald Hoffman was a college sophomore when he collaborated with his supervisor in determining the heats of formation of two substances. The report of their work appeared in the *Journal of Research of the National Bureau of Standards.*

At the end of the summer, each trainee is interviewed by his division adviser and the training officer to determine how successful the training has been from the employee's point of view. The interviewers give him some idea of his progress and may make recommendations on his future course of work and study. The project leader or the student himself may recommend transfer to another division for the following summer to better serve the student's talents and interests. If

Jack Tech, a Harvard student, adjusts a microtherm apparatus in the air gap of a 38,000 oersted magnet. He is preparing to make a Zeeman spectograph of a gas enclosed in a tube, which is out of sight between the poles of the magnet. This technique separates the spectral lines so as to permit a picture of the electronic structure of the gas atoms.

the summer scientist expects to return the following year, he is encouraged to go on educational leave instead of resigning at the end of his tour of duty. Such an arrangement simplifies reemployment and retains the student on the Bureau's mailing list so that he continues to receive the *NBS Technical News Bulletin* and the employee newsletter, *The NBS Standard*.

During this past summer several students participated in an out-of-hours reading-improvement course offered at the Bureau, while others enrolled in evening courses at nearby universities. But the program was not confined to work and study. Recreational activities included a picnic in honor of the trainees, divisional trips and parties, and student participation in Bureau softball, tennis, and golf teams.

In line with the program's aim to enlist permanent technical personnel, trainee appointments are limited to science majors planning careers in the fields of research carried on at the Bureau. A particular demand exists for physicists, chemists, metallurgists, and electrical and electronic engineers (table 2).

Last year 148 students came from 33 colleges, representing 24 States and the District of Columbia, to join the Washington staff. Of these, 21 were members of the high-school Science Honor Group. Of the students interviewed at the end of that summer all had satisfactory, or better, performance records; 60 percent had "excellent" or "outstanding" records; 82 percent were judged to have excellent potential for becoming scientific leaders; 93 percent were recommended for return to the division where they worked during 1955; and 100 percent were recommended for reemployment.

Improved Thermistor Bridge for RF Power Measurements

As part of a program of rf power standards development at NBS, an improved rf-power-measuring bridge has been designed and built by P. A. Hudson, I. S. Berry, and others of the High Frequency Electrical Standards Section at the NBS Boulder Laboratories. Using only one thermistor, the bridge combines simplicity of operation with greater accuracy over a wide range.

The operation of a power-measuring bridge is based on the equivalent heating effect of d-c power and rf power when both are dissipated in a purely resistive load. A temperature-sensitive resistor such as a thermistor or a Wallaston wire forms one arm of a Wheatstone bridge circuit which is biased with d-c power until the bridge is balanced. When rf power is fed into the thermistor simultaneously with the d-c bias power, the bridge becomes unbalanced and a quantity of d-c power must be withdrawn to effect a rebalance. The quantity of d-c power withdrawn is equated to the rf power (for the case of an equal arm bridge) as follows:

$$P_{rf}=\tfrac{1}{4}(I_1^2-I_2^2)R=\tfrac{1}{4}(2I_1-\Delta I)\Delta IR$$

where I_1 and I_2 are respectively the d-c basis currents before and after rf power is fed into the thermistor, $\Delta I=(I_1-I_2)$, and R is the bridge resistance at balance.

Usually direct measurements of I_1 and I_2 are made. This results in large errors when the rf power level is small because the above equation involves the difference between two large quantities I_1^2 and I_2^2. To alleviate this problem, it is the usual practice (an inconvenient one) to use several bolometer or thermistor elements with various sensitivities to cover the power range from microwatts to milliwatts.

The approach used in the present improved design eliminates the difficulty by measuring the differences, ΔI, directly, and at the same time making available a very simple and relatively foolproof circuit arrangement. The principle is to use a fixed total amount of direct current, furnished by a constant current source, and to divert the necessary part of this current from the bolometer bridge into a shunt resistor, where it can be measured directly. The more constant the current source, the greater the accuracy, especially at low power levels, and thus the over-all usable range is increased.

A simple constant-current source can be improvised from a regulated laboratory d-c power supply and a series resistor whose value is about 100 times that of the bridge resistance. The maximum change in the total current due to load impedance changes will then be only about 1 percent. Accuracies of the order of 5 percent or better can be obtained with such a source and a 50-ohm single-thermistor bridge at power levels of about 1 to 100 milliwatts.

With the NBS bridge, 100 μw to 100 mw can be measured with a single thermistor; the accuracies vary with power level and are 5 to 0.05 percent at the corresponding limits. The improvement over present-day commercial bridges is about 10 to 1 in the power range and as much as 100 to 1 in percentage accuracy.

Much better current regulation as well as stability can be obtained by using a well designed constant-current source. The source in use at the Bureau (a special electronically regulated power supply) has a regulation of 1 part in 10^5 for load variation from zero to 100 ohms while the stability is ± 1 part in 10^5 per hour. Stabilities of ± 1 part in 10^6 have been observed over periods of from 5 to 10 minutes. With this source, rf power levels at the thermistor from 100 milliwatts down to 100 microwatts were measured with respective accuracies of 0.05 to 5 percent.

The design of this bridge circuit readily permits incorporating a self-balancing feature by having the amplified output of the bridge control the amount of shunt current. The improvement over present-day commercial bridges is about 10 to 1 in the power range and as much as 100 to 1 in percentage accuracy, with the greatest improvement at low levels.

NBS To Be Relocated

A TRACT of approximately 550 acres of land near Gaithersburg, Maryland, has been selected for relocation of the Washington laboratories of the National Bureau of Standards. The move will permit the Bureau to plan new buildings to replace present research facilities, which over the past 50 years have become inadequate for current needs.

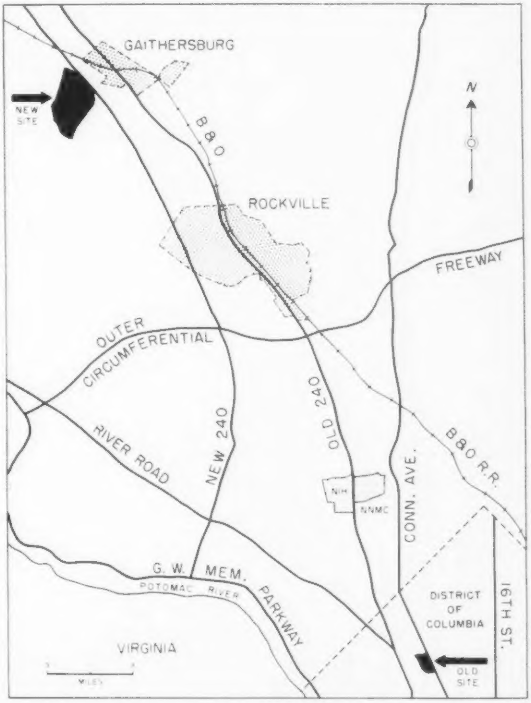
The new site was selected after careful consideration as most suited to the special requirements of the Bureau's scientific and engineering programs. The choice was based upon a number of factors, including accessibility by railroad and highway as well as topography for certain technical projects.

The Congress appropriated funds for site acquisition and preliminary planning early in June after details about the proposed site had been presented to House and Senate Appropriations Committees. Plans for the site have been given to the National Capital Planning Commission and to the Regional Planning Council, and it is expected that these groups will work with the Bureau in utilizing the land. The General Services Administration will participate in planning and will supervise construction. Transfer of operations to the new location is expected to be completed in about 5 years.

The Bureau has occupied its present site on Connecticut Avenue in Washington since 1903. During that time its responsibilities have greatly increased, largely as a result of the rapid expansion of technology and the growth of scientific research. Extensive programs of research and development must now be conducted in the physical sciences and engineering to meet the needs of science and industry for new and improved standards and measurement methods. The new site will enable the Bureau to plan for a more up-to-date plant consistent with its continually increasing responsibilities.

Many of the buildings on the present site are temporary in nature, and even the permanent buildings are outmoded from the viewpoint of modern technology. Renovation and modernization of this plant would be very costly, amounting to more than half the estimated cost of a complete new facility. Space for further expansion is also lacking on the present site.

It is expected that the new location will make possible a more modern research operation in structures that can be very efficiently managed. In addition, the new site will provide the benefits of a rural location where scientific programs can be undertaken without interfering in community life and without urban interference to important Bureau projects. The rural location will remove the Bureau's work from the variety of mechanical, electrical, and atmospheric disturbances present in a city and will reduce the effect of these forces upon precise scientific measurements.



The new Bureau site near Gaithersburg, Maryland, is shown at upper left. At lower right is the present site within the District of Columbia. On U. S. Route 240 are the National Institutes of Health and the National Naval Medical Center. In addition to existing highways, the map shows the new U. S. Route 240, now under construction, and the proposed Outer Circumferential Freeway and George Washington Memorial Parkway.

In addition to its Washington laboratories, the Bureau maintains a major research center in Boulder, Colorado, and 20 widely scattered field stations. The Boulder Laboratories are concerned with radio propagation research, radio standards, and cryogenic engineering. Most of the field stations are engaged in gathering data on radio propagation.

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Contents

Publications of the National Bureau of Standards

Journal of Research of the National Bureau of Standards, volume **57**, No. 2, August 1956 (RP2694 to RP2700 incl.). Annual subscription $4.00.

Technical News Bulletin, volume **40**, No. 8, August 1956. 10 cents. Annual subscription $1.00.

Basic Radio Propagation Predictions for December 1956. Three months in advance. CRPL 144. Issued August 1956. 10 cents. Annual subscription $1.00.

Journal of Research, volume **57**, *No. 2, August 1956. 60 cents. Single copies of Research Papers appearing in the Journal are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies of a Research Paper. Request for the purchase price should be mailed promptly to that office.*

Research Papers

RP2694. Thermal properties of aluminum oxide from 0° to 1,200° K. George T. Furukawa, Thomas B. Douglas, Robert E. McCoskey, and Defoe C. Ginnings.

RP2695. Stress-strain relationships in yarns subjected to rapid impact loading: 4. Transverse impact tests. Jack C. Smith, Frank L. McCracken, Herbert F. Schiefer, Walter K. Stone, and Kathryn M. Towne.

RP2696. Thermal expansion of polytetrafluoroethylene (Teflon) from −190° to −300° C. Richard K. Kirby.

RP2697. Preparation of D-arabinose-5-C^{14} from D-glucose-6-C^{14}. Horace S. Isbell, Nancy B. Holt, and Harriet L. Frush.

RP2698. Thermal expansion of binary alkali silicate glasses. Herman F. Shermer.

RP2699. Investigation of an alternating-current bridge for the measurement of core losses in ferromagnetic materials at high flux densities. Irvin L. Cooter and William P. Harris.

RP2700. Ionization and dissociation of the trifluoromethyl halides by electron impact. Vernon H. Dibeler, Robert M. Reese, and Fred L. Mohler.

Circulars

C573. Phase of the low radiofrequency ground wave. J. R. Johler, W. J. Kellar, and L. C. Walters.

Patents

(The following U. S. Patents have been granted to NBS inventors. Assigned to the United States of America, as represented by the Secretary of the Department noted in parentheses.)

No. 2,740,755. April 3, 1956. Electropolishing with phosphorus acid. Dwight E. Couch and Abner Brenner. (Commerce).

No. 2,747,030. May 22, 1956. Stabilized synchronous amplifiers. Richard G. Nuckolis. (Commerce).

No. 2,748,269. May 29, 1956. Regenerative shaping of electric pulses. Ralph J. Slutz. (Commerce).

No. 2,749,596. June 12, 1956. Method of making titanium dioxide rectifiers. Robert G. Breckenridge. (Commerce).

No. 2,750,753. June 19, 1956. Self-powered liquid oxygen pump and vaporizer. Richard W. Armstrong. (Navy).

No. 2,751,552. June 19, 1956. Thickness gage for metallic coatings. Abner Brenner and Billy J. Wagoner. (Commerce).

No. 2,752,435. June 26, 1956. Commutator switch for use in flow measurement apparatus. Henry P. Kalmus and Albert L. Hedrich. (Commerce).

Publications in Other Journals

Standard test for photoflash cells. H. J. DeWane. Mag. of Standards (70 E. 45th St., New York 17, N. Y.) **26**, No. 5, 135 (May 1955).

How strong must a building be? George N. Thompson. Mag. of Standards (70 E. 45th St., New York 17, N. Y.) **27**, No. 3, 68–71 (Mar. 1956).

How the National Bureau of Standards contributes to building codes. James P. Thompson. BOCA News. (Building Officials Conference of America, Inc., 110 E. 42d St., New York 17, N. Y.) **4**, No. 12, 1–3 (May 1956).

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